Engineering Notes

ENGINEERING NOTES are short manuscripts describing new developments or important results of a preliminary nature. These Notes cannot exceed 6 manuscript pages and 3 figures; a page of text may be substituted for a figure and vice versa. After informal review by the editors, they may be published within a few months of the date of receipt. Style requirements are the same as for regular contributions (see inside back cover).

Active Control of Asymmetric Forces at High Incidence

Yang Yongnian,* Yu Xinzhi,† Li Jianying,‡
and Wang Zongdong§
The Aerodynamic Research Institute
Northwestern Polytechnical University
Xi'an, China

Introduction

ACTIVE control technology (ACT) involving automatic control theory, computer science, electronics, and aerodynamics has many applications for high-performance aircraft and missiles. Various systems, such as active control augmentation, direct force control, gust alleviation, and flutter suppression, have been widely investigated.[1-3]

In high-incidence flight, symmetrical aircraft and missiles may be subjected to asymmetric forces because of vortex wake asymmetry. These forces are almost impossible to control because of their large magnitudes coupled with sudden changes in direction.[4-7]

Various methods have been used to solve this problem, such as roughness strips, fixed or hinged strakes, spinning nose devices, active blowing devices, and changed nose shapes.[7-17] This paper describes an investigation combining the spinning nose concept[10] with a microcomputer active control device for the optimization of the asymmetric force-alleviating spin rate for various flight conditions.

Model and Equipment

An experimental investigation of active control of asymmetric side forces at high incidence was carried out in a 1.5-m open-jet single-circuit low-speed wind tunnel at NPU. The model, shown in Fig. 1, is a 60-mm-diameter cylinder with a tangent-ogive nose (slenderness ratio = 3.5). The total length of the model is 510 mm. The rotating nose tip is driven by a variable-speed dc motor mounted in the model.

The Reynolds number based on the freestream velocity and diameter of the model was around 1.5×10^5. The model was sting-supported at its base. The angle of sideslip was zero. Aerodynamic forces were measured by a six-component mechanical-strain gauge balance.

The vorticity distribution in the wake was measured by a photoelectric digital vorticity meter consisting of two major parts: a vane and a digital frequency meter.[18,19] The vane, as shown in Fig. 2, has four perpendicular blades and can rotate around its axis. When the vane makes a cycle around its axis, an impulse signal is produced by a photodiode mounted on the axis. The number of signals per second is recorded by a digital frequency meter. The local vorticity in the flowfield is proportional to the rotation rate of the vane.

Received Dec. 4, 1986; revision received June 30, 1987.

*Associate Professor.
†Lecturer.
‡Assistant Engineer.
§Engineer.

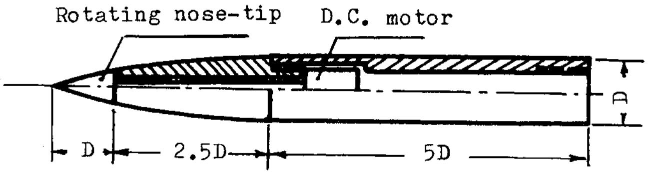

Fig. 1 Sketch of the model.

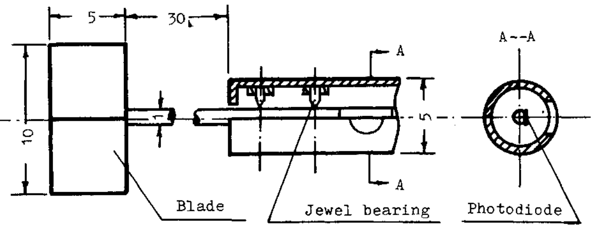

Fig. 2 Sketch of the vane for vorticity measurement (mm).

The microcomputer is the main component of the active control system. The side force element of the balance was used as a side force sensor. The angle-of-attack sensor was connected to the angle-of-attack mechanism of the wind tunnel. The signals from these sensors were transformed to digital quantities by analog to digital converters and conveyed to the microcomputer. The digital output of the microcomputer was then reconverted to an analog signal to control the speed of the dc motor. Since the rotating nose tip can influence the asymmetric force, it is regarded as a control element.

The Mechanism of Alleviation of Asymmetric Forces with a Rotating Nose Tip

It is well-known that the asymmetric forces are very sensitive to slight geometric asymmetries at the nose of the model.[4-7] The magnitude and direction of the forces vary with the orientation of the nose due to the corresponding variation of the vortex flow separation asymmetry and corresponding flow patterns in the wake.[10,11] When the nose of the model rotates very slowly, the vortex flow pattern changes slowly, and the side force on the model has approximately the same magnitude in either direction. Both the period of the variation of the wake vortex and its displacement during one revolution of the nose decrease with increasing nose rotating speed. At high rotating speeds there is not enough time for the vortices to develop fully, and the asymmetry of the wake decreases significantly, as well as the magnitude of the asymmetric forces.

In order to verify the preceding explanation, the vorticity fields on the lee side of the model were measured. The results are shown in Fig. 3. It can be seen that with the nose tip rotating, the asymmetry of the wake vortex distribution and the local vorticity value decrease significantly. Based on these results, the rotating nose tip can be regarded as an aerodynamic control element of the active control device. The asymmetric force on the model can be reduced to a minimum value if the rotating speed of the nose tip is adjusted properly.

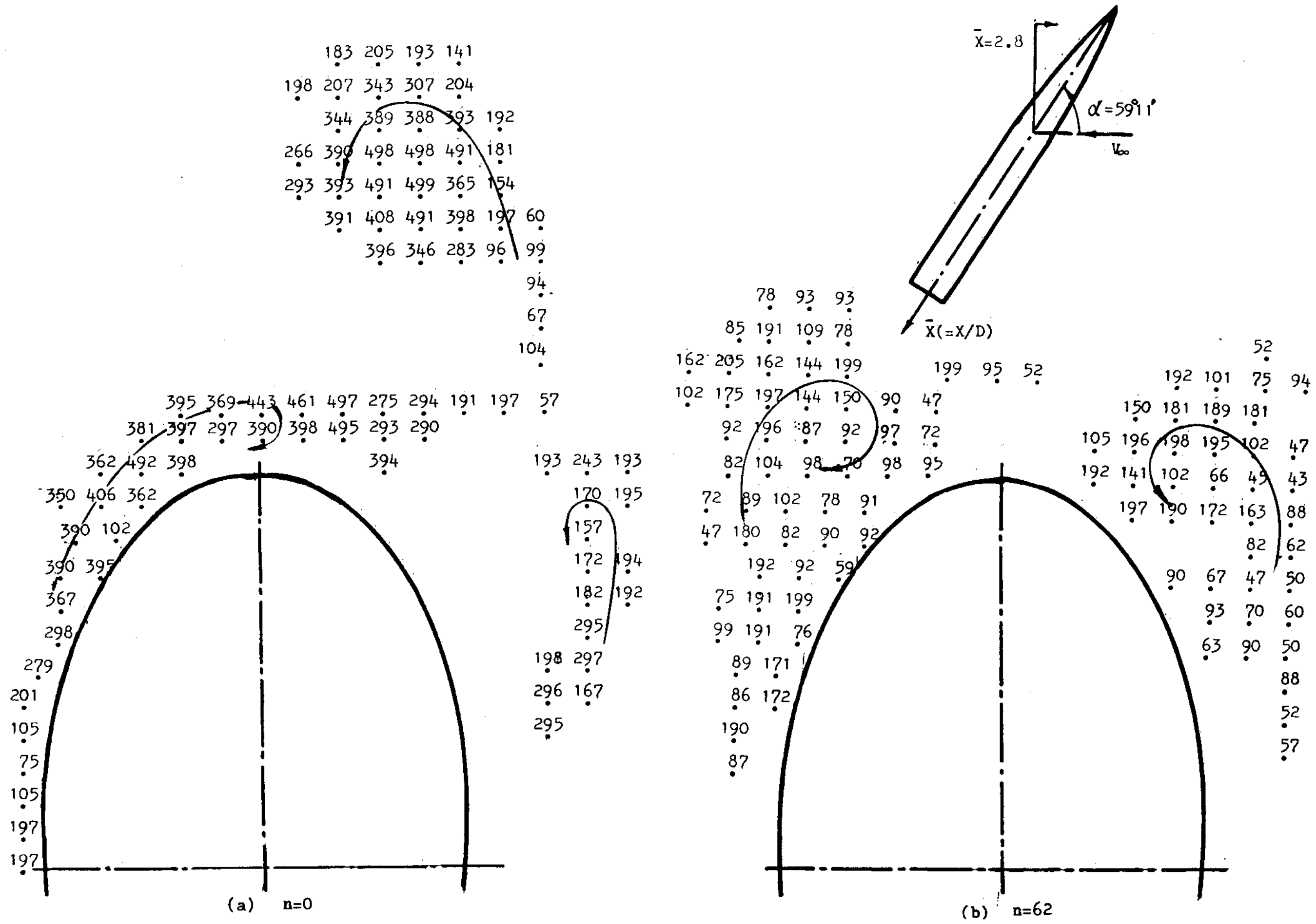

Fig. 3 Measurements of wake voritices at $\bar{x} = 2.8$ and $\alpha = 59.2$ deg 11 ft. The numbers are rotating speed of the vane n_v (Hz).

The Principle of the Active Control System

In this paper two active control schemes are adopted: 1) Adaptive Control (A.C.) and 2) Function Feedback Control (F.F.C.). Their principles are as follows:

Adaptive Control

The rotating speed of the dc motor varies continuously in its working range. Both the side force on the model and the rotating speed of the dc motor are recorded by the microcomputer. Thus, the rotating speed of the dc motor corresponding to the minimum side force is found. When the angle of attack is changed, the process is repeated. Hence, the minimum asymmetric side force on the model at each angle of attack can be obtained automatically.

Function Feedback Control

The rotating speed of the nose tip corresponding to the minimum side force was measured beforehand at various angles of attack, and the results were stored in the microcomputer. When the signal of the angle-of-attack sensor is fed into the microcomputer, it will send a previously specified voltage to the dc motor. Thus, the nose tip can maintain the appropriate rotating speed, producing the minimum side force at each angle of attack.

Results and Discussion

To obtain the control law for active control of asymmetric forces at high angles of attack by wind-tunnel testing, the side forces were measured at each angle of attack for various nose tip rotation speeds. The results are shown in Fig. 4. From these data, the relation between the angle of attack and the rotating speed of the nose tip corresponding to the minimum side force, i.e., the control law of the F.F.C. program, can be found, as is shown in Fig. 5. The control law of the A.C. program, deduced by the microcomputer, is also shown in Fig. 5. The side forces and yawing moments vs α in both programs are shown in Fig. 6.

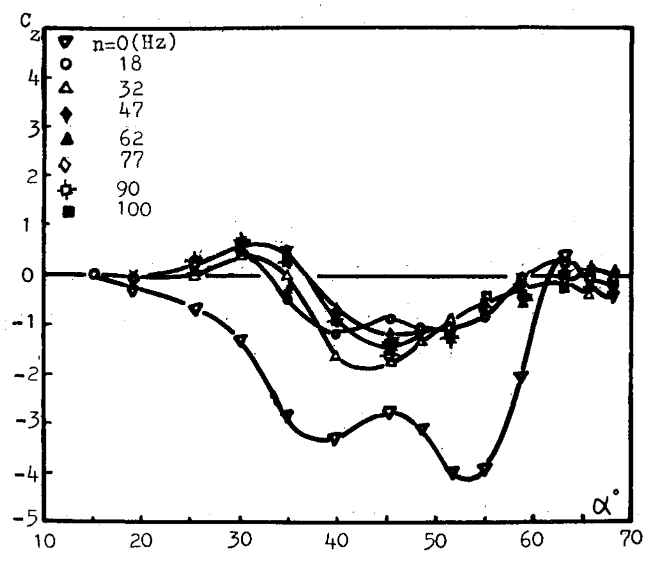

Fig. 4 Measured side force $C_y = f(\alpha)$ for different rotation rates.

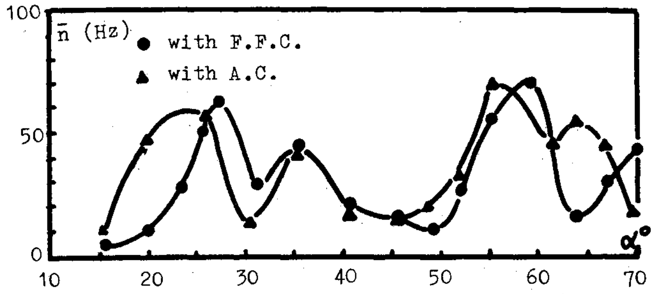

Fig. 5 Rotation rate for minimum side force condition, $\bar{n} = f(\alpha)$.

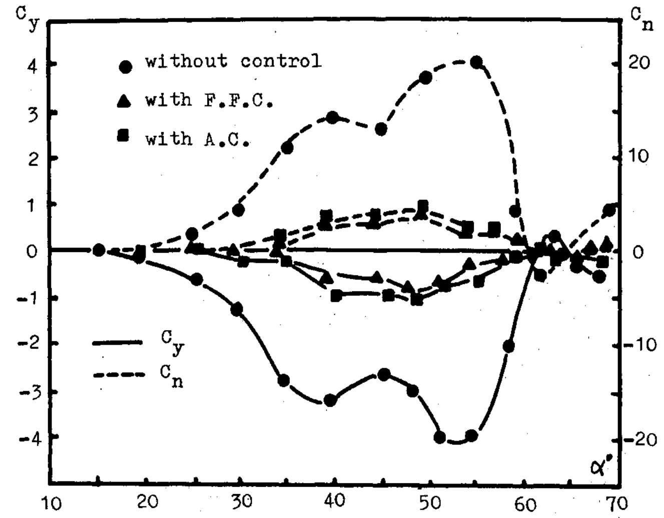

Fig. 6 Side force $C_y = f(\alpha)$ and yawing moment $C_n = f(\alpha)$ with and without active control device.

The investigation leads to the following conclusions:

1) The asymmetric side force and yawing moment can be reduced significantly by nose tip rotation.

2) The active control programs developed can automatically limit the side force on the model to its minimum magnitude.

3) In the F.F.C. and A.C. programs, the response times for changing the angle of attack are 2 and 15s, respectively.

For further investigation of the practical application of A.C.T. to the control of asymmetric forces on actual flight vehicles at high incidence, some important subjects should be considered:

1) In the wind-tunnel test, the model should be supported in such a manner that it can move freely in lateral translation, yawing, and rolling, even in pitching and vertical translation, permitting the dynamic response of a model with an active control device to be measured. Perhaps accelerometers and/or gyroscopes should be used as sensors of the asymmetric forces.

2) Because the A.C. program can find the control law automatically, it could probably be applied to aircraft if the response time were reduced.

3) Other aerodynamic control elements, such as controllable strakes and active blowing jets, should be investigated.

References

[1]"Active Control Systems for Load Alleviation, Flutter Suppression and Ride Control," AGARD AG 1875, 1974.

[2]Williams, P.R. G. and Campion, B.S., "Impact of Active Control Technology on Airplane Design," AGARD CPP-157, Oct. 1974.

[3]"Structural Control," *Proceedings of the Symposium at the University of Waterloo,* Edited by H.H.E. Leipholz, Ontario, 1979.

[4]Pick, G. S., "Side Forces on Ogive Cylinder Bodies at High Angles of Attack in Transonic Flow," *Journal of Spacecraft and Rockets*, Vol. 9, June 1972, pp. 389–390.

[5]Moss, G. F., "Some UK Research Studies of the Use of Wing-Body Strake on Combat Aircraft Configurations at High Angle of Attack," AGARD CP-247, 1979, pp. 4.1–4.19.

[6]Peake, D. J. and Owen, F.K., "Control of Forebody Three-Dimensional Flow Separations," NASA TM 78593, 1979.

[7]Almosnino, D. and Rom, J., "Lateral Forces on a Slender Body and Their Alleviation at High Incidence," *Journal of Spacecraft and Rockets,* Vol. 18, Sept.-Oct. 1981, pp. 393-400.

[8]Rao, D. M. and Huffman, J. K., "Hinged Strakes for Enhanced Maneuverability at High Angle of Attack," *Journal of Aircraft*, Vol. 19, April 1982, pp. 278–282.

[9]Kruse, R. L., "Influence of Spin Rate on Side Force of an Axisymmetric Body," *Journal of Aircraft*, Vol. 16, April 1978, pp. 415–416.

[10]Fidler, J. E., "Active Control of Asymmetric Vortex Effects," AIAA Paper 80-0182, 1980 (see also *Journal of Aircraft*, Vol. 18, April 1981, pp. 267–272).

[11]Ericsson, L. E. and Reding, J. P., "Aerodynamic Effects of Asymmetric Vortex Shedding from Slender Bodies," AIAA Paper 85-1797, 1985.

[12]Modi, V. J., Ries, T., Kwan, A., and Leung, E., "Aerodynamics of Pointed Forebodies at High Angle of Attack," *Journal of Aircraft*, Vol. 21, June 1984, pp. 428–432.

[13]Yongnian, Y., "The Alleviation and Control of the Asymmetric Load at High Angle of Attack," *Acta Aerodynamica Sinica*, No. 1, March 1985, pp. 112–116.

[14]Xinzhi, Y., Yongnian, Y., Ze, W., Daxuan, W., and Zongdong, W., "The Rotating Nose Method to Control Asymmetric Force at High Angle of Attack," *Proceedings of the Third Asian Congress of Fluid Mechanics*, Tokyo, 1986, pp. 531–533.

[15]Jorgensen, L. H. and Nelson, E. R., "Experimental Aerodynamic Characteristics for a Cylidrical Body of Revolution with Various Noses at Angle of Attack from 0 to 58 deg and Mach Number from 0.6 to 2.0," NASA TM X-3128, 1974.

[16]Keener, E. R., Chapman, G. T., and Kruse, R. L., "Effects of Mach Number and Afterbody Length on Onset of Asymmetric Force on Bodies at Zero Sideslip and High Angle of Attack," AIAA Paper 76-66, 1976.

[17]Luckring, J. M., "Theoretical and Experimental Aerodynamics of Strake-Wing Interactions up to High Angle-of-Attack," AIAA Paper 78-120, 1978.

[18]Dangxian, W., "Photoelectric Digital Vorticity Meter," Technical Rept. SHJ8106, Northwestern Polytechnical University, Feb. 1981.

[19]Wigeland, R. A., Ahmed, M., and Nagib, H. M., "Vorticity Measurements Using Calibrated Vane-Vorticity Indicators and Cross-Wires," *AIAA Journal*, Vol. 16, Dec. 1978, pp. 1229–1234.

Notice to Subscribers

We apologize that this issue was mailed to you late. As you may know, AIAA recently relocated its headquarters staff from New York, N.Y. to Washington, D.C., and this has caused some unavoidable disruption of staff operations. We will be able to make up some of the lost time each month and should be back to our normal schedule, with larger issues, in just a few months. In the meanwhile, we appreciate your patience.